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Smart Structural Control Strategies for Offshore Wind Power Generation with Floating Wind Turbines

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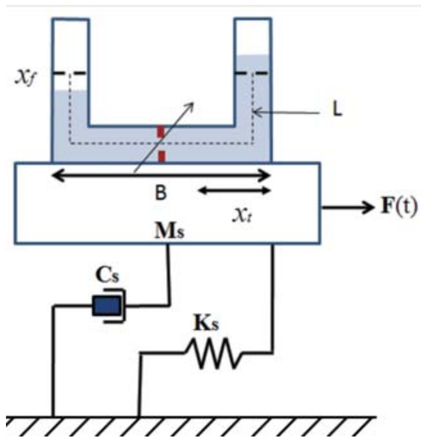
In recent years, wind energy is the fastest growing clean and renewable energy source in the world. However, most of the wind farm development has been limited to the land space and shallow water regions. Recently, several European countries (including Spain), USA and Japan started to plan floating offshore wind farms. In June of 2009, the first floating offshore wind turbine (Hywind) of the world was installed by Statoil-Hydro and Siemens on the coast of Karmøy, near the port of Bergen, Norway. In general, floating offshore wind farms are considered to be more difficult to design and install. However, in deep waters they are less sensitive to the space availability, noise restriction, and visual pollution, among others. Moreover, the wind power generation is more effective due to that floating offshore wind farm are exposed to a much stronger and steadier wind field.

Spain, as the second largest installed capacity in Europe, is known for its use of onshore wind. However, there is not any offshore wind farm installed in Spain yet. A recently published wind map by the Institute for Energy Diversification and Saving of Energy indicated that the offshore wind in Spain could also generate large amount of energy. According to Greenpeace, in the Iberian Peninsula it would be possible to create 25,000 MW by 2030, which would avoid the annual emission of 25 million tons of CO_2. The navy terrain in Spanish Mediterranean Sea wins a lot of depth moving a bit away from the coast. Thus, Spain is considered as one of the European countries with great interests in floating offshore wind farms. In fact, the Spanish government published an environmental strategy study of the Spanish coast, in delimiting the areas that meet the conditions for the installation of offshore wind farms and established a procedure for offshore wind farm installation larger than 50MW. Recently, Spain also identified some key floating structures for the future of offshore wind energy and added them to the technological development through the project "EMERGE", which is an initiative funded by the Ministry of Science and Innovation aiming to the installation of floating offshore wind farms in deep water. The Spanish government has proposed this Special Strategic Project Plan to generate awareness and position the companies and institutions in this new research fields. "ZEFIR" is another floating project under development in Catalonia, which aims to develop pioneer technologies for wind energy production by building a pilot plant for offshore wind farms, and raises the installation of multiple floating offshore turbines in deep water of Tarragona, Spain.

The development of offshore wind turbines with fixed support platforms is based on the experiences of onshore wind turbines. It has opened a relatively short path of success for the installation of offshore wind farms in shallow water. In a fixed offshore wind turbine, the high-frequency excitations caused by rotating blades and tower flexibility may cause resonance at its natural frequencies. Consequently, it may significantly shorten its fatigue life when the water depth increases. The floating support platforms provide with an effective solution to the installation of offshore wind turbines in deep water. In general, floating offshore wind farms installed in deeper (>40m) offshore areas are expected to be more economical than the fixed ones. For designing the floating wind farms, the existing technology and experience of offshore petroleum industry are directly applicable. Thus, if technology and infrastructure are fully developed, floating offshore wind farms are expected to produce huge amount of clean electricity at a competitive price compared to other energy sources. However, floating offshore wind farms may have some disadvantages: more transmission loss, more complex blade control due to body motions, larger inertia loading on tall tower caused by greater floater accelerations and possibly more expensive/complicated installation processes including mooring lines. Also, since floating wind turbines are directly exposed to the open ocean without any natural protection, they may have to endure harsher environments. In general, the natural frequencies of floating offshore wind turbines are typically much lower than those of the rotor-induced or the tower-flexibility-induced excitations. The possibility of dynamic resonance with the tower and blades is much less, with the exception of the TLP floating support platforms which are much stiffer in the vertical-plane. For other types of floating bases with softer mooring system, such as spar or semi-submersible, the low-frequency excitations related to the blade pitch-angle control may cause large-amplitude slowly-varying floater motions. Therefore, the accurate estimation of the coupling effects between the floater dynamics and tower-blade dynamics/control is very important in the optimal design of floating offshore wind turbines. Advanced control strategies are playing an important role in the overall stability of wind turbine systems to damp the undesirable structural resonances and to reduce the dynamic response to the wind turbulence and wave current. For floating support platforms, a big challenge will be in damping the roll motions, which are translations of the rotor in the plane of rotation. Especially, in contrast to the fixed offshore wind turbines, control systems should be used to limit the responses of the floating wind turbine and floater platform to the stochastic wave loading.

A major difficulty in the control of floating offshore wind turbine is the presence of the aerodynamic loads (wind turbulence) and hydrodynamic loads (wave current), which are generally stochastic ones. In this research, we will use the advanced control strategies to reduce the dynamic load responses of a floating offshore wind turbine taking into account the rotor dynamics, aero-dynamics, tower elasticity, floater dynamics and mooring-line dynamics. Among many structural control strategies, semiactive control technology is particularly promising for facing the engineering challenges such as the reduction of capital and maintenance costs, the elimination of external energy dependence, the increase of system reliability and robustness, and the implementation of non-traditional technology. This paper addresses the problem of mitigating the dynamic load responses of a floating offshore wind turbine, which might cause undesirable vibrations and affect the structure integrity and system performance. In the analysis and control design, the dynamics of floating offshore wind turbine assembly will be taken into account and new semiactive structural control laws will be developed for guaranteeing the stability and reliability. A Tuned Liquid Column Damper (TLCD) is used as a semiactive vibration control device situated at the wind turbine tower.



A static H_2/H_∞ output feedback control law is presented so as to achieve the simplicity of controller implementation and provide with the prescribed performance of the semiactively controlled system.